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Analogy, Complexity and Holism-Drawing as 3-D Modelling.

This article discusses drawings produced by the designer, Graham Whiteley, in the course of a 3-dimensional design project concerned with new forms of artificial limbs. This is complex, difficult and wide-ranging work extending over several years. The drawings throw light on the learning methods used by the design in early stages, the holistic approach adopted and the thinking of the designer at different stages of the work. The article considers the different approaches of industrial designers and engineers and contrasts modernist concepts of planning and more recent concerns with managing rapid evolution.

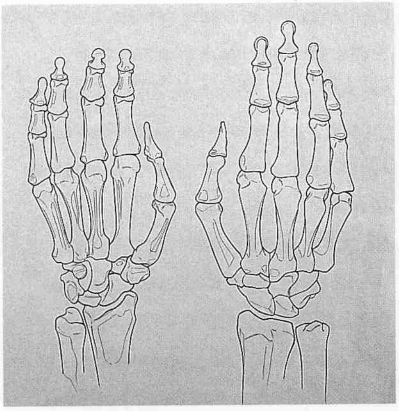


Fig. 1

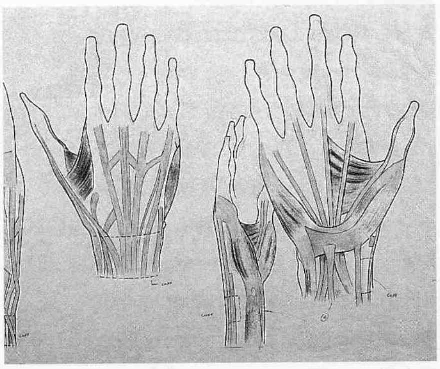


Fig. 2

Authors: Chris Rust and Graham Whiteley

Introduction and context of the project

The tradition of 3-dimensional design at Sheffield Hallam University emphasises exploration in 3D media, including CAD modelling, and it is unusual to focus heavily on drawing, although that is clearly an important aspect of any design activity. However, given the technical complexity of this project, the designer's ability to explore and resolve 3D problems on paper has been of great value in ensuring that designs are well resolved before effort is invested in physical prototyping. Another very important feature of this work has been the designer's use of drawing as a learning technique in gaining an understanding of anatomy.

The project is a research effort at Sheffield Hallam University and University of Sheffield, currently funded by the National Hospital Trust, to develop a set of design principles for an entirely new prosthetic arm.The main feature is that this will follow a very close analogy with the original anatomy to provide the possibility of natural movement and

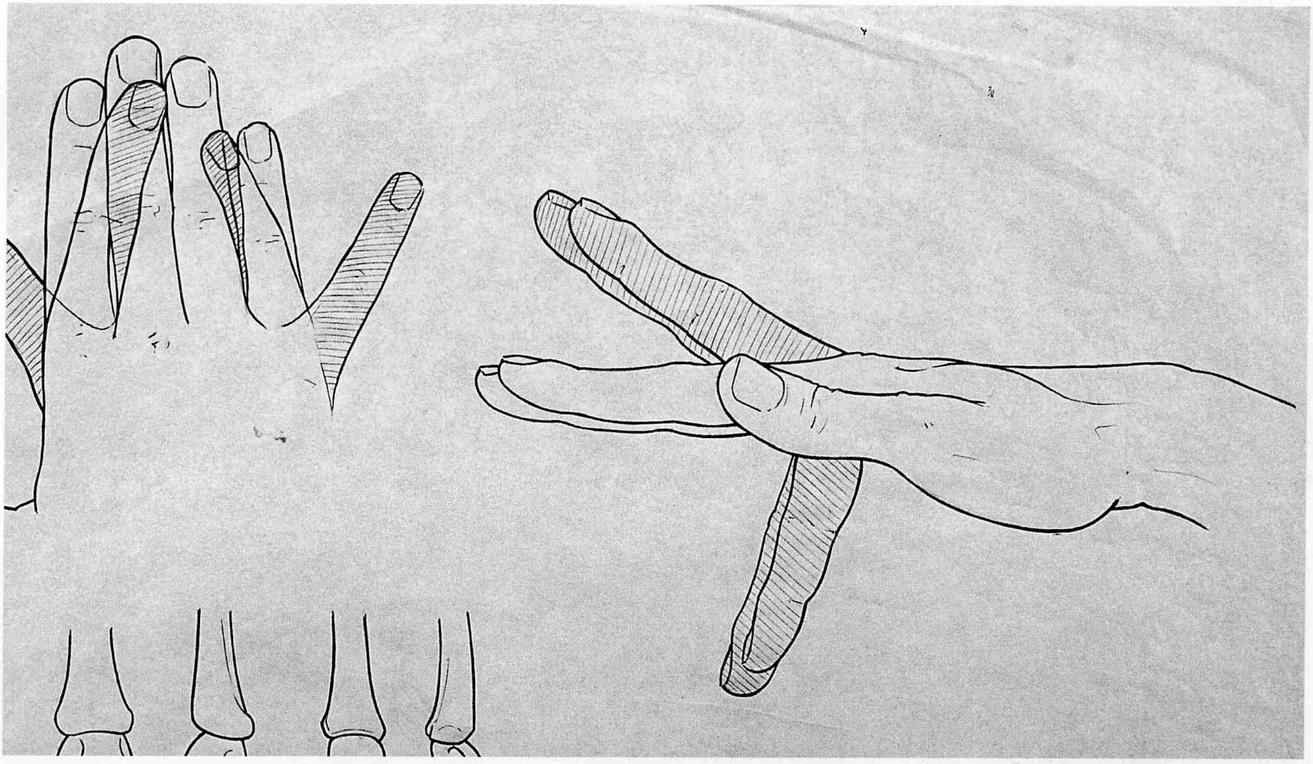


Fig. 3

greater functionality. Past designs are based on a simplistic functional analogy and do not meet the aspirations of the people who use them.

A feature of the project is that it puts creative industrial design activity at the centre of a multi-disciplinary approach with the intention that the creative work will stimulate the involvement of other specialists and the involvement of users and clinicians. Collaborators from a medical or engineering background are used to working in a reductive, analytical way to uncover new knowledge and it is hoped that an approach based on synthesis and a holistic viewpoint will be complementary and provide new points of departure for such specialists.

This is clearly a highly speculative project which assumes that a great deal of development in other fields will be needed. The current aim is to produce a fully articulated analogous mechanical "arm" which would demonstrate what is possible and provide a physical testbed for researchers in other fields such as "artificial muscle" and control systems. The project was initiated by Graham Whiteley and is being pursued by him through a PhD research programme which places an emphasis on research carried out through design practice where the creative work produced will provide the central outcome of the programme. A fuller description of the project has been published elsewhere.

The Drawings

The drawings shown are part of a large collection of sketches and diagrams produced during the project so far. They were mainly in pencil and ballpoint pen on A3 sized layout or bleedproof paper and were almost entirely produced for the designer's own purposes in thinking through design problems. They provide evidence of prolific and wide-ranging thinking which frequently steps outside the problem in hand to explore issues which are relevant but go well beyond the scope of the present project.

In the early stages of the project, the priority was to gain an understanding of the subtle details of the original anatomy, before any attempt could be made to design a set of analogous mechanisms. This was done by spending time in the anatomy teaching lab, normally used by physiotherapy students, observing and drawing skeletons and models as well as working from textbooks. Although there are many excellent anatomical illustrations available in textbooks, it was important that the designer developed his own understanding and processes of drawing provided the best way to do that. It is an interesting aspect of the project that, when problems arose with the design of the prototype mechanisms, a return visit to the anatomy lab and time spent on further drawings often revealed subtle aspects of the original anatomy which had not been taken account of in the design.

These drawings of the designer's hand (he is left-handed) Figs. 1,2 and 3 were produced to provide a measurable record of the articulations of his fingers, as well as developing an understanding of finger movements. Figs. 4 and 5 come from a concept development sheet for the mechanisms of the hand. Later on, once the technical ideas and dimensions of the mechanisms were better understood, the presence of a "real" hand in the drawings was less important. The drawing on the right, produced in the same period, was the first schematic expression of the whole design. The hand is reasonably well detailed (although nowhere near complete) and the rest is nothing like the eventual design but it representations of all the elements which will be needed and was an invaluable aid to longer term thinking.

The drawing of the ulna, (one of the bones of the forearm), Fig. 6 shows how the twin concerns of visualisation and technical precision run through all of this work. Accurate orthographic projections, showing up to 6 views of a bone, were produced. As well as accuracy, great attention was given rendering form detail since the precise nature and boundaries of the different surfaces of the bones were crucial. These drawings were then photocopied and used for the kind of dimensional and trigonometric analysis shown here.

One of the most difficult problems was to understand and reproduce the

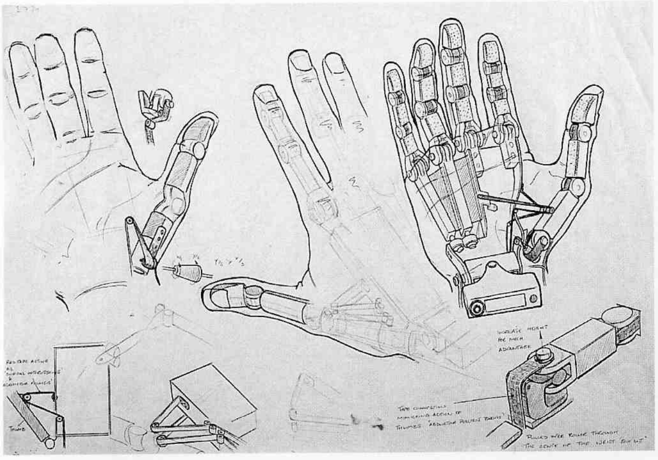


Fig. 4

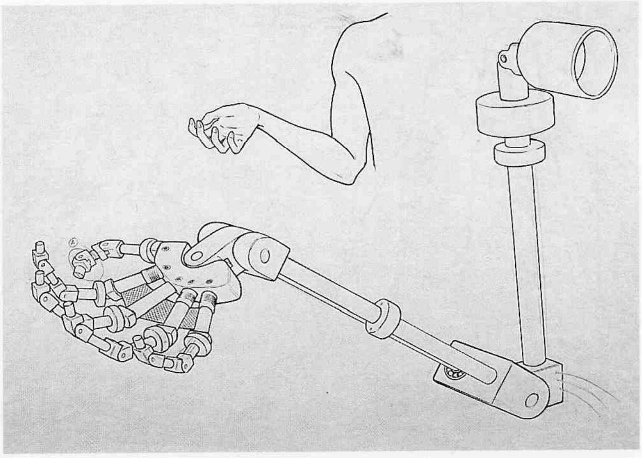
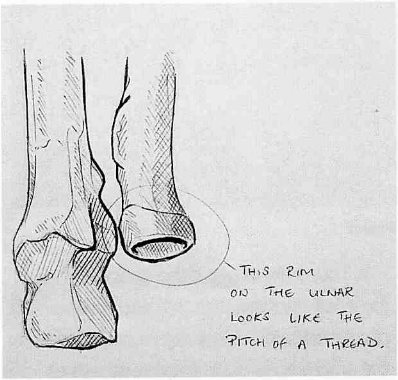


Fig. 5



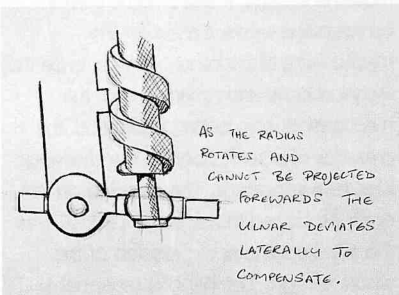


Fig. 7

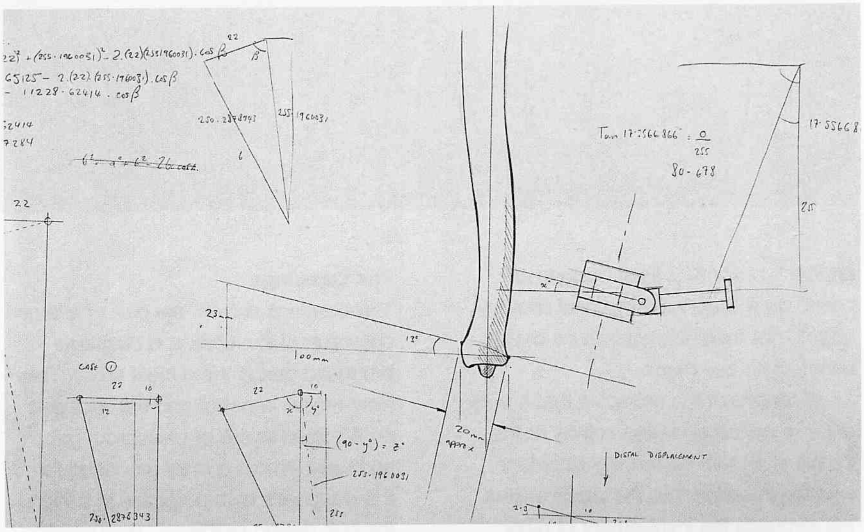


Fig. 6

mechanisms which rotate the wrist through the cooperative motion of the two bones (radius and ulna) of the forearm. In this study the rim of the "bearing" surface at the end of the ulna is observed to be similar to the pitch of a thread and the analogy is explored through a second drawing.Fig. 7 (the conclusion was that this was not a useful analogy)

The sketch sheet Fig. 8 gives an insight into the thought processes of the designer. To the left and centre are a number of mechanism sketches for various aspects of the design and these have an immediate relevance to the project in hand. However there are much longer term and speculative issues such as the possibility that an "artificial muscle" material may be available in the forseeable future. There are a number of such developments around the world but the designer is also pursuing his own chain of thought based on analogy as evidenced by the small diagram at top right (labelled "Myosin Molecular Ratchet") and the sketch lower down which looks like aset of caterpillar tracks. These are diagrammatic and mechanical analogies for micro-mechanisms at cellular level. This holistic thinking, considering many levels of the problem simultaneously, has been an essential feature of the project.

Fig 9 shows the elbow joint design as it approaches its final form, this has been the most challenging part of the project so far. The main elbow component on the left looks relatively simple but the pair of orthographic views to its right give an idea of the difficult articulation which it supports. Fig 10 shows the elbow joint clearly and confidently described with the ulna and radius attached below, but above it there is a much more sketchy drawing of an idea for attachment to the amputee's vestigial limb. Like the artificial muscle problem, this is outside the scope of the immediate project but the opportunity was taken to think it through and assess its implications for the design of the elbow.

Figs 11 and 12 are both drawings

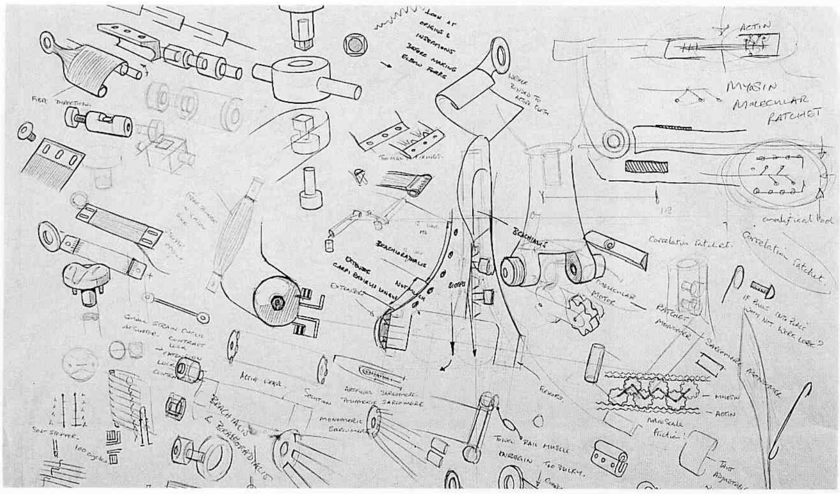


Fig. 8

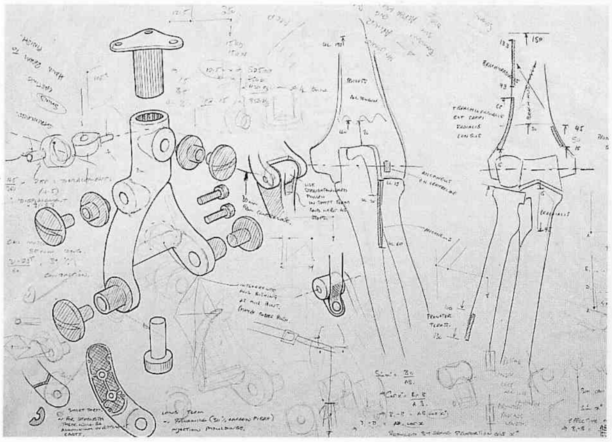


Fig. 9

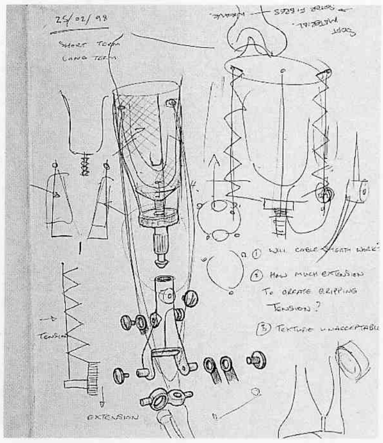


Fig. 10

from stages when fine detail was being resolved. On the left is a detail of the knuckle components and on the right a breakdown of the elements of parts of the elbow. At first glance this appears to be an exploded view of a complex assembly but in fact it contains more than one version of several components, providing a record of the main options and how they developed. This drawing started life as a much larger sheet of light pencil sketches, the parts seen here being inked over as the level of confidence increased and the most promising avenues were recognised.When similar drawings were shown to colleagues from engineering and medical backgrounds, there was often an assumption that these drawings were produced by 3D CAD modelling and the idea that somebody had drawn them with a pencil was difficult to digest. Similarly, when examples of thesedrawings were included in a scientific journal article, as evidence of thedevelopmental methods used in the project, one reviewer did not wish them published, pointing out that the drawings were untidy, included irrelevant material and the handwritten annotations should be replaced with proper type.On the other hand, the use of drawings has been very helpful when discussing ideas with collaborators. On some occasions, during technical discussions, the designer drew on his own hand to illustrate ideas or problems and this was very helpful for people who were not used to thinking 3-dimensionally. Unfortunately there is no record of any of these drawings.

Fig.13 is in complete contrast to most of the other examples. It is part of a sheet of working sketches produced for and during sessions in the workshop when a series of precision components were produced in metal and plastic. The paper is stained with oil and the drawings are produced with little of the care shown in the rest of the work, at this stage the design is thoroughly understood and the main need is to have a portable reference for key dimensions and some calculations on fit. The components are geometrically simple and appropriate for machining with conventional methods. Parts calling for a greater subtlety of form or complexity of detail are not produced this way - they are translated into 3D CAD models and then produced by CNC machining or a freeform fabrication process such as stereo-lithography.

Discussion

This series of drawings provides an opportunity to observe the processes which the designer works through in a creative 3D project with a large technical component. In this case the designer is extremely comfortable with drawing as a development medium, using it mainly as a method ofcommunicating with himself (most of the published outcomes of the project have been actual objects or the results of a variety of evaluation activities and very few drawings have been seen by anybody other than the designer)

This project is an example of a designer from a "creative" discipline taking a very pro-active role in an area which is commonly believed to be the

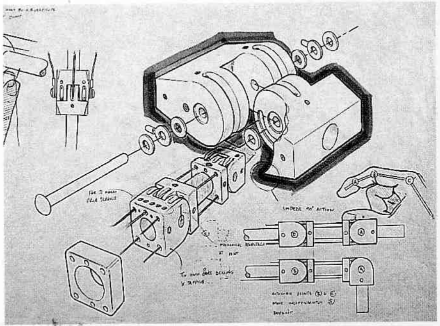


Fig. 11

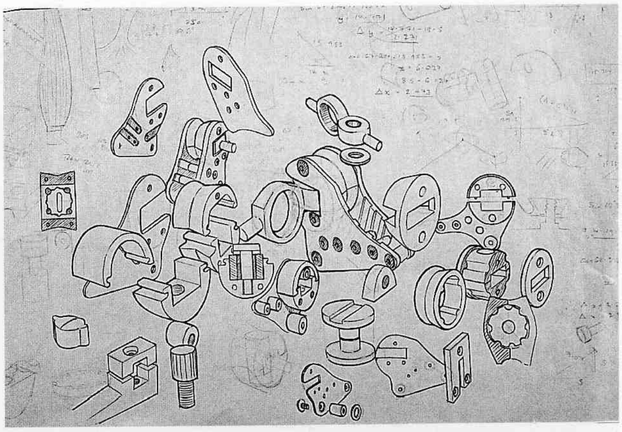


Fig. 12

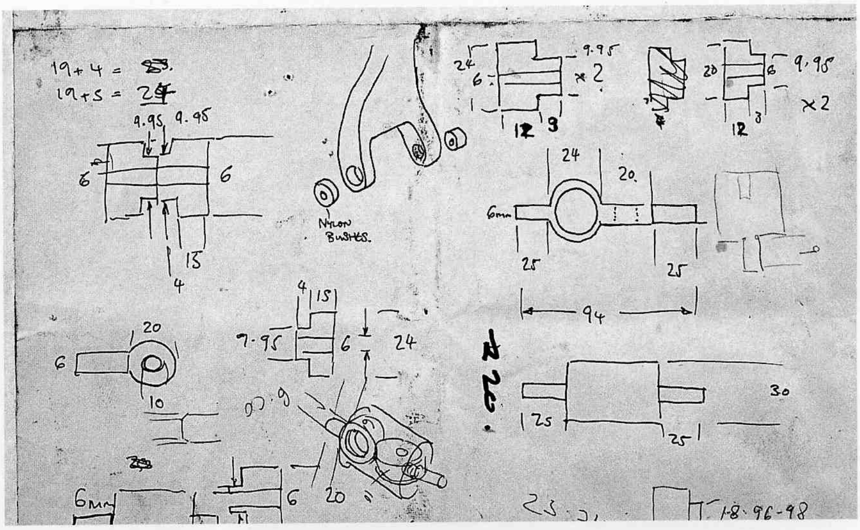


Fig. 13

province of engineers and it is interesting to reflect on developments in the practice of engineering which have created a vacuum which is being filled increasingly by industrial designers.

Some time ago, during a period when modernist thinking was focused on the idea of structured design methods, John Christopher Jones described the increasing use of complex abstract techniques as design moved away from evolution through craft making, starting with the use of drawings and going on to systems analysis. This movement today takes in increasingly abstract mathematical models to the point where an engineering colleague recently described a group of very able students as "knowing nothing about the real world except the equations which describe it." By contrast, Industrial Design has retained the use of craft processes and engagement with real objects and the iterative structure of this project has also ackowledged the importance of allowing evolution to take a hand. The current concern in industry with rapid prototyping techniques which allow faults in a design to be detected quickly and cheaply ("fast failure" rather that "right first time") indicate that pragmatic designers are looking for ways to speed up evolution rather than techniques for complex forward planning.

Drawing skills, both formal technical drawings and sketching, have played an important part in the work of the engineer in the past and this project illustrates their usefulness, especially in the processes of synthesis. This project was started, in part, because all the existing work on upper limb prostheses had been incremental, building on established designs, and there was evidence that, without some significant new principles, there would be no great improvement for people who need artificial limbs. The designer's use of drawing has been a central tool in generating a completely new approach to these devices which is holistic in that it integrates potential new technologies, ideas about "naturalness", a concern for effective manufacturing and cost and a view of a complete "product" as well as an understanding of detail.

Biographical Details

Chris Rust is Reader in Design at Sheffield Hallam University. His career started in with an apprenticeship in Marine Engineering followed by several years' experience in engineering design and project management. Having escaped from all that in his late twenties to become an itinerant musician he eventually studied Industrial Design (Transportation) at Coventry Polytechnic and has since worked as an independent design consultant and teacher.

Graham Whiteley is a graduate in Industrial Design from Sheffield City Polytechnic who has worked as a designer of museum exhibits. This led him to discover that he could not buy accurate components to build an articulated model of a person, providing the germ for his current research. He has been a researcher at Sheffield Hallam University since 1995, having previously pursued his interest in prosthetics as personal research.